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THE GEOLOGY OF PARAHYBA AND RIO GRANDE DO
NORTE, BRAZIL.

PLATES I-IV.

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INTRODUCTORY.

The data for the following paper was gathered in a series of three expeditions made into the states of Parahyba and Rio Grande do Norte. The actual time consumed in collecting the material dated from the latter part of March, 1912, until the middle of February, 1913. The writer was sent into the field by the Brazilian

government to investigate the practicability of drilling wells and procuring water throughout the two states mentioned above. The notes on the geology were made in connection with and as a part of that work.

The topography of Parahyba and Rio Grande do Norte is not one of strong contrasts. There are no great mountain ranges and no large rivers. In fact there is not a single stream in either state that can be depended upon to flow during the entire year. The climate, for the most part, is hot and dry—a somewhat unexpected phenomenon for a region in 5 degrees south latitude. The rainfall is irregular, being copious one year while the next it may fail entirely. Moreover, it is seldom distributed over a considerable time or area, but is more likely to fall locally in a torrent, and then after a dry period of weeks, there is another torrent.

The states of Parahyba and Rio Grande do Norte have comparatively few inhabitants and their struggle for life during the last 200 years forms one of the epics of South America. Driven from their homes time after time by thirst and hunger, they have always returned and are still in the sertão,¹ enduring untold privations and waiting with infinite patience the arrival of happier times.

The topography of the accompanying map is based on the "Mappa dos Estados do Ceará, Rio Grande do Norte e Parahyba," by H. E. Williams and R. Crandall. With the exception of the coastal sediments south of Natal, which are shown according to J. C. Branner, the geology is the writer's own work. The region covered is an extensive one and the work was done by means of horseback meanders, a pedometer, pocket compass, aneroid, and hand level. In general, however, the geological areas shown are accurate within the map scale used.

The writer wishes to acknowledge his indebtedness to Professors J. C. Branner, Orville A. Derby, and to Dr. M. Arrojado Lisboa, for valuable help and suggestions. Among the papers consulted, two were found to be of especial value, namely, "The Geology of the Northeast Coast of Brazil," by J. C. Branner and "Geographia, Geologia, Supprimmento d'Agua, Transportes, e Açudagem," by Roderic Crandall.

¹"Sertão" is the word used in northeastern Brazil to denote the back country or the interior.

TOPOGRAPHY.

The states of Parahyba and Rio Grande do Norte form three general topographic divisions. The first is a zone of low coastal sediments of Cretaceous and Tertiary age. The second is a great plateau which rises from the western edge of the coastal plain and sweeps clear across the two states thus embracing more than two thirds of their area. The third division consists of a series of high serras which rise abruptly from the surrounding plain, and whose summits are often remarkably flat.



FIG. 1. Index map.

The coastal belt may be further divided into that part which immediately adjoins the sea, marked by shifting sand-hills, low swampy areas overgrown with mangroves and by general poverty in vegetation; and second, into the higher sedimentary land, the limestone and sandstone areas, usually covered by a dense caatinga² forest. This latter region includes the Chapadas of Apody and São Sebastião, rich fertile regions almost uninhabited. The topography of this sedimentary region, as a whole, has a low relief, the only prominent features being the line of sand dunes which stretches along the coast (especially prominent in the vicinity of Natal), and

² Caatinga is a Brazilian term for a low, brushy forest.

the low, plateau-like chapadas mentioned above. In the eastern part of Parahyba the coastal sediments are scarred by short streams which have narrow, fertile valleys and steep banks, where erosion has cut deeply into the soft beds.

The plateau region can be described briefly as a great rolling plain of hard, crystalline rock, covered irregularly by a growth of caatinga, dense or sparse according to the character and degree of decomposition of the underlying rocks. It covers by far the greater portion of the two states and ranges from an elevation of 100 meters near the contact with the sediments, to 300 meters further inland. It is in this region, locally known as the "alto sertão," that drought is most severely felt.

Rising abruptly from this undulating plateau and attaining a height of from 500 to 600 meters, is a series of serras which form the only relief in the monotonous topography. Most marked of these serras is the Planalto de Borborema with a mean elevation of about 500 meters, which reaches from the southern portion of Rio Grande do Norte, clear across the central portion of Parahyba and forms a part of the boundary of that state with Pernambuco. In the vicinity of Campina Grande it has a width of more than 100 kilometers but narrows to the north of there. The Serras Canabrava, Jabitaca, Baixa Verde and Teixeira form a part of the boundary referred to above.

From the Serra Teixeira there is a low line of mountains stretching away to the eastern part of Ceará. Some of the larger ones are the Serra Mellado, Serra Catharina and the Serra do Vital. There are several more, smaller and without names, significant only in that they form a part of a general structural feature. The Serra Santa Catharina is the most important of the mountains named and reaches a height of about 650 meters. To the north of this mountain line, beginning near Souza and stretching in a northeast direction almost to Catolé do Rocha, is a long mountain called the Serra Commissario. I did not cross this serra, but from a distance it appeared to be a series of small buttes rather than one great mountain.

Still further north of the Serra Commissario, and forming

a part of the division line between the states of Rio Grande do Norte and Parahyba, is another mountain range. Beginning with the Serras S. Miguel, Luiz Gomes, and Serra Padre, which mark the meeting point of the three states, Parahyba, Rio Grande do Norte, and Ceará, and stretching away in an easterly direction are the Serras Negra, Barriguda, Furada, Patú, and other minor ones. Between the end of this line and the northeast point of the Serra Borborema, here called Serra Mattos, lies the Serra João do Valle.

All of the mountains or tablelands thus far mentioned are more or less similarly constructed, that is, they arise abruptly from the surrounding plain, are usually flat-topped and are composed entirely of crystalline rocks; some of them have a core of granite. Other than the more important serras whose names have been given there are many small isolated peaks or serrotes of granite and gneiss which rise irregularly and sharply out of a rolling, caatinga-covered plain.

There is one other type of mountain found in these states illustrated by the Serras Martins, Porto Alegre, and João do Valle. The Serra João do Valle I did not visit but saw from a distance. Mr. Roderic Crandall³ describes it as being of the same structure as the others named. These serras represent an unusual phenomenon. They rise abruptly from the plain of Rio Grande do Norte, to an elevation of about 700 meters and their summits are remarkably flat-topped. The bulk of the mountains are composed of crystalline rock, nearly all schist with some gneiss, as is also the surrounding country. But their summits are capped with sandstone, about 50 meters thick. These three mountains, in so far as I have been able to determine, are peculiar in this respect.

DRAINAGE.

The drainage everywhere in Parahyba and Rio Grande do Norte flows to the east or northeast; in other words it takes the shortest course to the sea. Along the southern border of Parahyba the watershed marks the boundary between that state and Pernambuco.

³ Roderic Crandall, "Geographia, geologia, supprimento d'agua, transportes, e açudagem," page 6, Rio de Janeiro, 1910.

Of the various streams the rivers Apody (or Mossoró), Assú, Ceará Mirim, and Parahyba, are the most important. The Rio Jaguaribe in the southern part of Ceará might also be included, for the territory drained by it is physically the same and has passed through the same history as the adjoining region in Rio Grande do Norte. Not a single stream in the entire territory under consideration is perennial. The reason for this is partly the scarcity and irregularity of the rainfall, partly the hard, impervious nature of the rocks, and partly the hot, dry climate.

GEOLOGY.

For the purposes of the present study the geological formations represented in the states of Parahyba and Rio Grande do Norte may be classed in two groups as follows: first, the ancient (Archean to early Paleozoic) rocks which have been called the Brazilian complex by Dr. Branner;⁴ second, the comparatively modern (Mesozoic to Recent) rocks which we call the sedimentary series.

The Brazilian complex consists of crystalline rocks (mainly gneiss) and schists disposed in inclined beds which are quite thickly threaded with dikes and bosses of various eruptives, among which granites predominate.

The rocks of the second group consist mainly of sandstones, limestones, and incoherent sand and clay deposits (including dunes), all of them disposed in horizontal or approximately horizontal beds.

In general terms the two groups as shown on the accompanying map are evenly distributed. With the exception of a comparatively narrow strip along the coast and a few isolated spots in the interior, the whole of the two states is made up of the crystalline rocks. No attempt at a systematic classification of this division will be made here. I have not had the time nor the opportunity to do more than to observe some of the broader features. However, to intelligently understand the geologic conditions in this region, it is necessary to know that the rocks of the Brazilian complex cover practically all of the interior; and that the more recent sedimentary beds along the coast have been formed by the deposition of sedi-

⁴ "Geologia elementar," 2d ed., pp. 286-289. Rio de Janeiro, 1915.

ments derived from this original land mass. It is necessary also, to know that these rocks are not homogeneous but that they are hard here and soft and decomposed a few feet away; that they have been crushed, metamorphosed and recrystallized to a remarkable extent, and that one may find a hard granite "serrote" standing out in the midst of an area of soft schist. Everywhere the rocks are cut by quartz veins which range from a few centimeters to half a meter in diameter and occasionally there are pegmatite veins.

Mr. Roderic Crandall in his paper entitled "Geographia Geologia, Suppimento d'Agua, Transportes e Açudagem" makes a further division which he calls the "Series Ceará." I have not made this distinction, but have included the rocks of the Ceará series under the more general head of the schists of the Brazilian complex. However, they have a few distinguishing characteristics which I shall give briefly. The Ceará series, where it is distinguishable, seems to be composed of acid rocks, usually of a light color. They contain more or less kaolin and clay and in some cases have a peculiar earthly appearance. On weathering off they do not weather into rounded boulders with smooth surfaces, but outcrop in jagged exposures and the boulders, large and small, have sharp edges—not rounded ones. The Ceará series usually presents a schistose appearance and in places according to Mr. Crandall, may contain lenses of hard, vitrified sandstone. In other places there are masses of limestone completely isolated in areas of schist. However, there does not seem to be any systematic separation of this series from the other rocks and it is often, if not usually, impossible to make any distinction at all. No attempt has been made by anyone to map them separately. Hence, although all of the schists are probably not strictly crystalline, I have included them with the crystalline rocks of the Brazilian complex.

In regard to the distribution of the granites, I have already said that they form the axes of some of the principal serras. Also, they are especially noticeable along the contact of the crystalline mass with the sediments. In such a vicinity the former usually takes the shape of rounded boulders and bosses of granite and gneiss. Small patches of granites, however, are found occasionally outcropping

throughout the crystalline areas of Parahyba and Rio Grande do Norte.

The sedimentary series, as previously indicated, may be separated into three divisions. First, there is a bed of rather coarse-grained and sometimes conglomeritic sandstone which directly overlies the crystalline rocks. In color it is usually brick-red but may also be yellow or white. The color is probably due to varying amounts of iron stain. The contact between this sandstone and the crystalline rocks was first seen where it crosses to the southeast side of the Rio Jaguaribe, a few kilometers to the south of Limoeiro. From there it passes close to the village Taboleiro d'Areia and continues to follow the general direction of the Chapada do Apody, but about 9 kilometers back to the southwest of the Chapada, until it reaches Passagem Funda. At this point the contact is 15 kilometers to the south. From here it continues to follow the direction of the escarpments of the Chapadas São Sebastião and Vacca Morta, always from 8 to 12 kilometers to the south of them. These last two named escarpments are in reality only a continuation of the scarp of the Chapada do Apody. At Assú the contact passes almost through the city and from there on to Natal it is very regular, always approach-nearer to the coast as we go south. It passes very close to the village Garapeba, and to the railway station Baixa Verde, passes just north of Taipú, south of Ceará Mirim, and is seen about 5 kilometers west of Macahyba. From this point south it is noted a few kilometers west of S. José, passes through Curimatú, goes close to Espírito Santo, and Pedra de Fogo. Thus the sandstone is exposed in a narrow strip from near Aracaty, at least to Natal and probably on down into the state of Pernambuco. A section at right angles to its length would show a consistent width of exposed area from 8 to 12 kilometers. The only reliable structure that I have seen in this rock was in the vicinity of Apody, along the escarpment of the Chapada do Apody, and near Assú, along the Lagoa Piató. In these places the sandstone beds dip from 3 to 8 degrees to the northeast or toward the sea. There are some good exposures near Garapeba also, but little structure is evident there. For the most part the exposed sandstone is seen on the surface as an incoherent, heavy, yellowish-

brown sand, with no hard rocks at all. No fossils have ever been found in this sandstone. The beds are at least 30 meters thick.

Directly overlying the sandstone is a bed of hard, fine-grained limestone which is usually of a grayish or yellowish color. It is exposed in a continuous strip from near Aracaty to Natal and is known to exist in several places between Natal and Parahyba. It is not unlikely that this strip of limestone continues on uninterrupted into the state of Pernambuco. As is shown on the accompanying map, the escarpment of Apody, beginning in the vicinity of União, follows a general southwest direction until it reaches a point about due west of Apody. There it swings sharply about and follows a northeast direction to Passagem Funda. At Passagem Funda the river Apody has cut squarely through the chapada and the east side of the river is known as the Chapada do São Sebastião while the west side retains the name of Apody. In reality the two low plateaux comprise a single physical feature. The escarpment of the Chapada do São Sebastião is a continuation of the scarp of the Chapada do Apody. This former makes a detour to the south and then follows a northeast direction to the village Rua da Palha. Here the same thing has happened as was noted at Passagem Funda. The Rio Upanema has cut through the Chapada do São Sebastião and the part of the serra which lies to the northeast of the river has become known as the Serra or Chapada da Vacca Morta. The escarpment of the Serra Vacca Morta trends a little to the northeast from Rua da Palha as far as the northern margin of the Lagoa Piató, and finally becomes lower and lower until about 6 kilometers east of the lagoa, it merges with the low hills that make up the topography of that region. The remarkable thing about this escarpment which varies from 30 to 100 meters in height, is that it marks the contact between the sandstone and the limestone. Everywhere along its entire length the base of the escarpment is sandstone while the top is limestone. The whole surfaces of the Chapadas of Apody, São Sebastião and Vacca Morta, are limestone. From the Lagoa Piató to Natal the contact between the sandstone and limestone has been only approximately located. It crosses the Rio Assú about 9 kilometers north of the city of that name and continues in a general easterly direction. Near the fazenda Sant'Antonio, 30 kilometers to

the southeast of Assú, the contact is exposed again. Thereafter it was found about 4 kilometers south of Baixa Verde (the village—not the railway station), and again a little to the north of the railway station—Itapassaróca. At Ceará Mirim the limestone is 31 meters below the surface (near the church), and it has been noted about 20 kilometers west of Natal, near Macahyba. South of Natal the writer has not explored the limestone, but Dr. J. C. Branner⁵ reports that it is found near São José, Goianinha, Pequiry and Parahyba. Hence it is probable that the same geologic relations exist to the south of Natal, as are known to exist to the north.



FIG. 2. Section across the Chapada do Apody.

The limestone exposed in the strip above mentioned has a varying width, which reaches its maximum in the vicinity of Mossoró. Here a cross section would show a width of at least 70 kilometers. At Assú probably 25 kilometers would cover it. From Baixa Verde a section east would show the limestone to be about 16 kilometers wide while in the vicinity of Natal it is probably less than 10 kilometers across.

The only place where the structure was clearly seen in the limestone was along the scarp of the Chapada do Apody and along the Rio Apody, from Passagem Funda to São Sebastião. There, rock dips toward the northeast; in places it is horizontal. At the fazenda Sussarana, 23 kilometers northeast of Apody, and again near the village São Sebastião, Mr. Crandall, in the paper previously referred to, reports that he observed the sandstone underlying the limestone. This means that in spite of the apparent seaward dip the beds are horizontal, or approximately so. Furthermore, a well has been drilled in Mossoró to a depth of 45 meters. The first 30 meters were in limestone and the last 15 in sand. Judging from this the

⁵ J. C. Branner, "Geology of the northeast coast of Brazil," *Bulletin of Geological Society of America*, Vol. XIII., pp. 93-95. Rochester, 1902.

same horizontal relation exists clear to Mossoró, for if the sandstone dipped uniformly seaward, even at an angle of one degree, it must in the 60 kilometers from Passagem Funda to Mossoró attain a considerably greater depth than 30 meters. The limestone has a thickness of between 30 to 50 meters. This estimate is based upon the exposures along the Rio Apody and upon two wells drilled, one in Mossoró above mentioned, and the other in Macáu. The well in Macáu showed the limestone to be 44 meters thick. The age of these limestones lies between the late Cretaceous and early Tertiary. Mr. Crandall⁶ reports fossils from them (these fossils are in the museum of the "Serviço Mineralógico" in Rio de Janeiro), and I have found a few.

Finally, overlying the limestones and extending on to the sea, is the third division of the sedimentary rocks, a more recent deposit, mostly sands and clays. The surface of this deposit is very sandy but when drilled into it is seen to contain a great deal of clay. The sand is calcareous in places. I have not seen any bedded rock between the limestone and the ocean but in some places there are patches of hard, sandstone boulders, often of a conglomeritic nature. The best exposures of these recent beds were seen during a trip from Lagoa dos Mattos to Areia Branca. From this first named place on to Mutomba, and again for two kilometers at the Morro do Thibáu, the sandstone is exposed in a bluff which varies in height from 15 to 20 meters. This rock usually has a belt of conglomerate at the base about 3 meters thick. Over this is a highly colored sandstone, rather hard and cemented with iron. Next there is a soft, marly sand, whitish and usually from 2 to 3 meters thick and without bedding planes. Over all are dunes of medium-grained, reddish-brown, unconsolidated sand. The whole bluff is highly colored and may show shades of brown, red, purple, lemon color and white. These beds nearly all contain more or less iron and lime and in some localities contain a great deal of earthy matter including kaolin and clay.

Further down the coast just south of the village of Touros,

⁶ Roderic Crandall, "Geographia, geologia, supprimento d'agua, transportes e açudagem," Publication of the Ministerio da Viacão e Obras Publicas, p. 31. Rio de Janeiro, 1910.

there is an exposure of yellow, coarse-grained sandstone with beds almost horizontal or dipping gently toward the sea. Fifteen kilometers further south there is a bluff about 3 meters high composed of a sandy clay, white, brown, and reddish colors. It very much resembles the bluff noted near Lagoa dos Mattos.

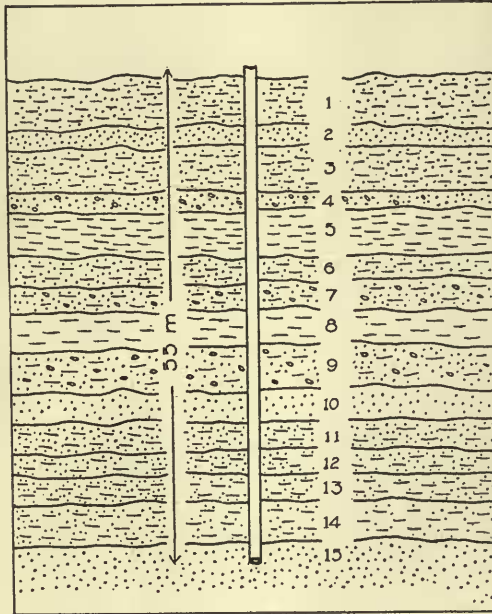


FIG. 3. The log of a typical well drilled in Natal, Rio Grande do Norte.

- | | |
|---------------------------------------|---------------------------------------|
| 1. Fine sand and clay. | 9. Sand and clay with quartz pebbles. |
| 2. Yellow sand. | 10. Yellow sand. |
| 3. Sand and clay. | 11. White sand with clay. |
| 4. Sand and clay with quartz pebbles. | 12. Yellow clay with sand. |
| 5. Clay. | 13. Red sand with clay. |
| 6. Sand and clay. | 14. Coarse sand with clay. |
| 7. Sand and clay with quartz pebbles. | 15. Coarse sand. |
| 8. Clay. | |

These deposits of sediments stretch in an unbroken strip from near Aracaty and probably further north, to Recife and probably further south. Their width varies: At Mossoró it is about 35 kilometers, at Macáu 22 kilometers, at Ceará Mirim 25 kilometers, at Natal about 20 kilometers and at Parahyba about 20 kilo-

meters. Their thickness increases as the coast is approached. At Areia Branca they have a thickness of at least 90 meters, at Macáu of 106 meters, and at Natal of at least 108 meters. I have never found any fossils in them, but Dr. J. C. Branner⁷ describes fossils in yellowish, calcareous sandstone along the coast at Ponta de Pedras, which he refers to the Tertiary. It is very probable, though of course not certain, that these beds are to be correlated with the sands and clays here described in Parahyba and Rio Grande do Norte.

The geologic history of this part of the coast of Brazil, basing our opinion upon the information already given, must have been about as follows: the rocks of the basal complex or the crystalline mass after a long period of erosion were finally submerged along the coast of Parahyba and Rio Grande do Norte during Cretaceous or Pre-Cretaceous times. The sea encroached on the land, much further than the present contact between the crystalline and sedimentary areas. It was during this first period of subsidence that the coarse-grained sandstone was deposited. Following this deposition a moderately pure limestone was laid down directly on top of the sand. Whether or not the land rose and the sandstone was subjected to erosion before the limestone was deposited, is not known definitely. The exposures of bedded sandstone are few, but wherever noted the strata of sand and limestone were conformable. Therefore, I am of the opinion that both were laid down during the same period of deposition, but that the contact marks a great change in physical conditions. Following this period the land rose. Apparently there was little disturbance for the beds are horizontal or they dip gently toward the sea. Considerable erosion must have taken place at this time for the limestone is worn very thin in places. During Post-Cretaceous times the land along the coast was submerged again and the more recent beds of sand and clay were deposited. Physical conditions must have again changed for the absence of calcareous matter in these latter beds show that animal life was scarce. Once more the land rose and has probably remained above the sea from that time until the present day. The surface of

⁷ J. C. Branner, "Geology of the Northeast Coast of Brazil," *Bulletin of Geological Society of America*, Vol. XIII., p. 47. Rochester, 1902.

the sand and clay deposits is more or less calcareous due to the lime-laden waters which pass over it, but the rocks a short depth below the surface are quite free from lime.

With the exception of the region about Mossoró and Assú the entire series of sedimentary rocks seems to be deposited in a fairly even line down the coast, the belt always becoming a little narrower toward the south. In the locality excepted there is a large basin inland. This can readily be explained by the nature of the drainage in that region. The three rivers Jaguaribe, Mossoró and Assú, are the largest along this part of the coast, and although they drain a large area their mouths are close together. Naturally in their immediate vicinity erosion was deeper and more general than in areas of lesser drainage. Hence, when the land sank the water was able to reach much further inland in this vicinity than in any other along the coast of Parahyba and Rio Grande do Norte, and the subsequent deposition covered a correspondingly larger territory.

Other than the sedimentary rocks along the coast there are several areas of stratified rocks, smaller and completely isolated, in the states of Parahyba and Rio Grande do Norte. Chief among these is the sandstone basin of the Rio do Peixe. Beginning at the approximate juncture of the Rio Piranhas with the Rio do Peixe and extending

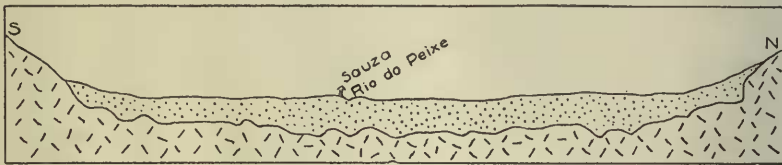


FIG. 4. Section across the sandstone basin of the Rio do Peixe, Parahyba.

over the divide into the head waters of the Rio Pendencia, a distance of 80 kilometers, there is a basin of reddish sandstone. The basin has a varying width which averages between 9 and 12 kilometers for the entire length, and has, moreover, a long arm which extends more than 12 kilometers up to Belém. It is an isolated area of sandstone in the midst of a vast stretch of crystalline rocks. The typical rock is a reddish and rather fine-grained sandstone, which, in the upper part of the basin, or roughly that part above Souza, is very common

and forms most of the valley floor, as well as the low hills well up toward the contact. As a general thing, however, the margins of the basin, or the part nearest the contact with the crystalline rocks, are composed of a coarser sandstone than the parts further down. In fact, the part nearest the contact is often a conglomerate, having small quartz pebbles, some the size of a hen's egg, imbedded in the sand. As a rule these sandstone beds dip gently to the south or a few degrees to either side of south. There is also evidence of a small syncline near the southern boundary of the valley. This syncline was shown near Acauan and again near São João in relatively the same position. However, it is small and is not likely to prove to be of any economic importance. The reddish and yellowish sandstone is interbedded with a likewise reddish clay. This clay covers so large an area that it must be taken into consideration. In appearance it is very much like the sandstone but of a finer grain. In several places in the valley it was found plainly interbedded with the sandstone. It is most common in the lower part of the basin, that is, it is found from one end to the other but in any one cross-section of the valley the clay would be more likely to be found near the river or in the lower part. The whole of this deposit of sediments is intergraded between a coarse sandstone of a conglomeritic nature, a medium-grained sandstone, a fine-grained sandstone of a partially clayey nature, and a typical clay. At times one may find all these different grades of rocks interbedded in one place.

So far as I know no fossils have ever been found in these rocks. The sandstone very much resembles that which underlies the limestone in the coastal belt, and it is provisionally referred to the Cretaceous. There is a possibility of its being connected with the sandstone of the Serra Araripe. There is also a possibility of its having been connected with the sandstone of the coastal belt. Indeed, it is difficult to account for its presence on any other hypothesis.

The Serras of Martins, Porto Alegre and João do Valle are a series of sandstone capped mountains which rise abruptly to a height of 650 to 700 meters. The last named of these was not visited by the writer. The first two have a layer of hard, quartzitic, coarse-grained sandstone which attains a maximum thickness of about 50 meters, and which lies horizontally on the crystalline rocks. No

fossils have been found, but it is not improbable that this sandstone was also once connected with that nearer the coast. The bases of the Serras Martins and Porto Alegre, are formed of old metamorphic schists. There is a mass of isolated limestone near the base of the Serra Martins. So far as I have been able to ascertain, these sandstone capped serras, the sandstone basin of the Rio do Peixe, and the coastal belt of sediments, form the total of sedimentary areas in the states of Parahyba and Rio Grande do Norte.



FIG. 5. Section across the Serra Martins, Rio Grande do Norte.

One of the most interesting things in this connection is the relation of the geology to the topography. The crystalline area may usually be recognized by scattered serrotes of hard granite, by occasional mountains which rise abruptly from the surrounding plain, by great, gently undulating stretches, covered with a scattered growth, and by low ridges, steep-sided and rocky. On the other hand the sedimentary area is notable first of all for its vegetation, which assumes the form of an impenetrable forest: often there is a thick undergrowth from 3 to 4 meters in height. The only prominent topographic features are a few low ridges and the broad Chapadas of Apody and São Sebastião, which on the south, end in a low escarpment, but which on the north, slope gently toward the sea. Also, very noticeable are the short streams with their steep banks which cut cleanly through the soft sediments. These hard rocks and undulating plains of the crystalline complex which give rise to a rapid drainage, and the long, almost level stretches on the sedimentary areas, play an important part in the conservation of the water supply.

SUMMARY OF OBSERVATIONS ON THE GEOLOGY OF PARAHYBA AND RIO GRANDE DO NORTE.

1. The two great groups of rocks in the region covered are crystalline and sedimentary.

2. The crystalline division is mainly gneiss and schists and includes the ancient (Archean to Paleozoic) crystalline rocks with bosses and dikes of various eruptives. It covers the greater part of the states of Parahyba and Rio Grande Do Norte.

3. The rocks classified by Mr. Roderic Crandall as the Ceará series are here included with the schists, since they are usually in that form. These particular schists are not all crystalline schists and may include layers or lenses of quartzite and of limestone.

4. The granites form the axes of some of the principal mountains.

5. It is impossible in a short expedition to determine the distribution of the crystalline rocks. They have been metamorphosed and intruded to a remarkable extent, and they seem to have crystallized in a very irregular manner.

6. The typical vegetation on the crystalline area is a scattered growth of low trees and brush of small root development, called caatinga. Caatinga forests, however, are not confined to areas of crystalline rocks.

7. The topography is characterized by great undulating plains, abrupt mountains, rocky, steep-sided hills, and peaked serrotes.

8. The crystalline rocks have been subjected to great crushing forces. The schists usually stand at a high angle and the rocks are everywhere cut through by quartz veins which vary in width from a few centimeters to half a meter. Occasionally there are pegmatite veins.

9. The rocks are usually soft and decomposed to a depth of from 3 to 10 meters.

10. The sedimentary series forms the comparatively modern (Mesozoic to Recent) rocks.

11. It is confined for the most part to a comparatively narrow strip along the coast.

12. This series reaches the entire coastal length of the states of Parahyba and Rio Grande do Norte and varies in width from about 120 kilometers in the vicinity of Mossoró, to 30 kilometers at Natal and about 30 kilometers at Parahyba.

13. The sediments thin out on the interior side until their margin

becomes a series of isolated patches overlying the granites and gneiss.

14. The sedimentary rocks have three main divisions:—a deposit of sandstone, one of limestone, and a more recent deposit of sands and clays.

15. The sandstone directly overlies the uneven face of the crystalline rocks. It is of a medium grain, is conglomeritic in places, and is usually of a white or reddish color. It has a thickness of at least 30 meters and probably more. It is exposed in a continuous strip from near Aracaty to Natal and probably further south; its average exposed width is from 8 to 12 kilometers.

16. In general this sandstone dips gently to the northeast. No fossils are known to have been found in it, but on account of its association with the limestone, it is commonly referred to late Cretaceous or early Tertiary age.

17. The sandstone is overlain by a bed of hard, fine-grained, yellowish and grayish limestone.

18. The limestone is exposed in a continuous strip from near Aracaty to Natal and is known to exist in several places between Natal and Parahyba. Its width varies from about 70 kilometers in the vicinity of Mossoró, to 25 kilometers at Assú, and less than 10 kilometers at Natal. It has a thickness of from 30 to 50 meters.

19. In general the limestone dips gently toward the sea—to the northeast. It is of late Cretaceous or early Tertiary age.

20. The contact between the limestone and the underlying sandstone, is marked from União to Assú, by a low escarpment which varies in height from 30 to 100 meters.

21. The limestone in turn is overlain by a partially consolidated deposit of sands and clays. Where these beds are exposed along the coast they are highly colored and contain much iron.

22. The area of sands and clays is exposed in a continuous strip from north of Aracaty, to south of Recife. They have a width which varies from 35 kilometers at Mossoró, to about 15 kilometers at Parahyba. Their thickness at Areia Branca is more than 90 meters, at Macáu it is 106 meters, and at Natal it is more than 108 meters.

23. At only one or two places along the shore are these sedi-

ments consolidated, and the structure when it is reliable shows horizontal bedding. I have not found any fossils in these beds but Dr. J. C. Branner reports fossils from similar beds at Ponta de Pedras which he refers to Tertiary age. It is not unlikely that these beds (in Parahyba and Rio Grande do Norte), are of the same age.

24. The Serras of Porto Alegre and Martins are capped with layers of quartzite, about 50 meters thick. Mr. Roderic Crandall reports that the Serra João do Valle is a similar mountain.

25. No fossils have been found in the sandstone of the above named serras.

26. The valley floor of the basin of the Rio do Peixe is composed of a reddish sandstone, conglomeritic in places and interbedded with a reddish clay. This area is from 9 to 12 kilometers wide and is about 80 kilometers long. It is entirely surrounded by crystalline rocks.

27. The age of this sandstone of the Rio do Peixe is provisionally referred to the Cretaceous, but so far as is now known no fossils have been found in it.

28. It will be noticed that practically the entire sedimentary belt along the coast is tilted gently toward the sea.

29. There is a series of shifting sand dunes along the coast especially noticeable in the vicinity of Natal.

30. There are many clay beds in the sediments along the coast. Some of them may be of economic value.

DESCRIPTION OF PLATES I.-IV.

PLATE I.

Geologic map of the states of Parahyba and Rio Grande do Norte, Brazil.

PLATE II.

A. Part of the Chapada do São Sebastião, showing the topography and the dense caatinga growth.

B. Exposure of limestone near Passagem Funda, Rio Grande do Norte.

PLATE III.

A. Isolated serrote of granite in the midst of an area of schist and gneiss, near Martins, Rio Grande do Norte.

B. Exposure of sandstone along the Chapada do Apody, near Passagem Funda, Rio Grande do Norte.

PLATE IV.

A. Serra do Porto Alegre, Rio Grande do Norte. The flat summit is of sandstone which rests on crystalline rocks below.

B. Part of the limestone scarp of the Chapada do Apody showing a luxuriant growth of vegetation.